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EFFECTIVE USE OF PRINCIPAL COMPONENT ANALYSIS WITH HIGH
RESOLUTION REMOTE SENSING DATA TO DELINEATE HYDROTHERMAL
ALTERATION AND CARBONATE ROCKS

SANDRA C. FELDMAN, Mackay School of Mines, University of
Nevada-Reno, Reno, NV 89557, USA

ABSTRACT

Methods of applying principal component (PC) analysis to high resolution remote sensing imagery were examined. Using Hot Creek Range, Nevada Airborne Imaging Spectrometer (AIS) data, principal component analysis was found to be useful for removing the effects of albedo and noise and for isolating the significant information on argillic alteration, zeolite, and carbonate minerals.

The most effective technique for using PC analysis for mineralogical discrimination was to perform three separate PC analyses using as input the first 16 AIS bands, 7 intermediate bands, and the last 16 bands from the 32 flat-field-corrected bands between 2048 and 2337 nm. Most of the significant mineralogical information resided in the second principal components. PC color composites and density sliced images provided a good mineralogical separation when applied to the Hot Creek AIS data set.

Although computer-intensive, the advantage of principal components analysis is that it employs algorithms which already exist on most image processing systems.

INTRODUCTION

Very effective software packages and algorithms have been developed specifically for use with high resolution remote sensing imagery (Goetz and others, 1985; Mazer and others, in press; Lyon and Lanz, 1985). Some of these packages, however, are not easily implemented with many users' existing image processing hardware configurations, and the software is often not compatible with other image processing software packages without a significant amount of reprogramming. The objective of this paper is to suggest methods for analyzing high resolution remote sensing data, specifically Airborne Imaging Spectrometer (AIS) imagery, that can take advantage of algorithms which already exist on most image processing systems. Principal component (PC) analysis is one such method.

Principal component analysis has been successfully used with Landsat Thematic Mapper (TM) imagery and TM simulator imagery to differentiate geologic units and to identify hydrothermally altered areas (Abrams and others, 1983; Conel and Alley, 1985). The effectiveness of this method with Airborne Imaging Spectrometer (AIS) data was tested during this investigation using 32 of the 128 bands from the Hot Creek Range, Nevada AIS-1 data set. These 32 bands contain the most important mineralogical absorption features in the 1200 to 2400 nm wavelength range. The data set has a 9.3 nm spectral sampling interval and a 12 m spatial resolution.

The Hot Creek AIS site is located in the Tybo mining district and contains hydrothermally altered and unaltered Paleozoic carbonate and clastic rocks, and Tertiary rhyolitic ash-flow tuffs. From field mapping, laboratory work, and measurements on samples collected along the flight line with an IRIS spectroradiometer, the ash-flow tuffs were found to be altered to clay, zeolite, and silica minerals (Feldman and Taranik, [a], in press). Kaolinite and calcite are widespread in the Music Canyon area, and kaolinite, montmorillonite, and clinoptilolite are common in the Red Rock Canyon area.

AIS METHODOLOGY

The 32 spectral bands between 2048 and 2337 nm in the Red Rock Canyon and Music Canyon areas, Hot Creek Range AIS-1 data set, were used to test the effectiveness of principal component analysis. Spectra of kaolinite, montmorillonite, clinoptilolite, and calcite from samples along the AIS flight line, recorded with a GER IRIS spectroradiometer, are shown in Figure 1.

Signal-to-noise ratios calculated for AIS-1 data sets vary between 40:1 and 10:1 (Vane, 1986; Tucker and Vane, 1986). In order to remove systematic noise, to correct for variations in detector response, and to remove atmospheric absorption features and the effects of the solar irradiance curve, a flat field correction was applied to the "raw" AIS data prior to performing principal component analyses. The correction was performed by choosing a spectrally flat area in the alluvium and dividing the brightness value of each pixel in each band along the flight line by the average value of the flat field in that band. The flat field correction does not remove albedo, but alters the albedo, leaving a relative albedo component in the data.

The application of principal component analysis to AIS data was considered successful if localities containing kaolinite, montmorillonite, clinoptilolite, and calcite, as determined from field mapping and laboratory analyses, were separable from each other in images constructed with principal components. Because of

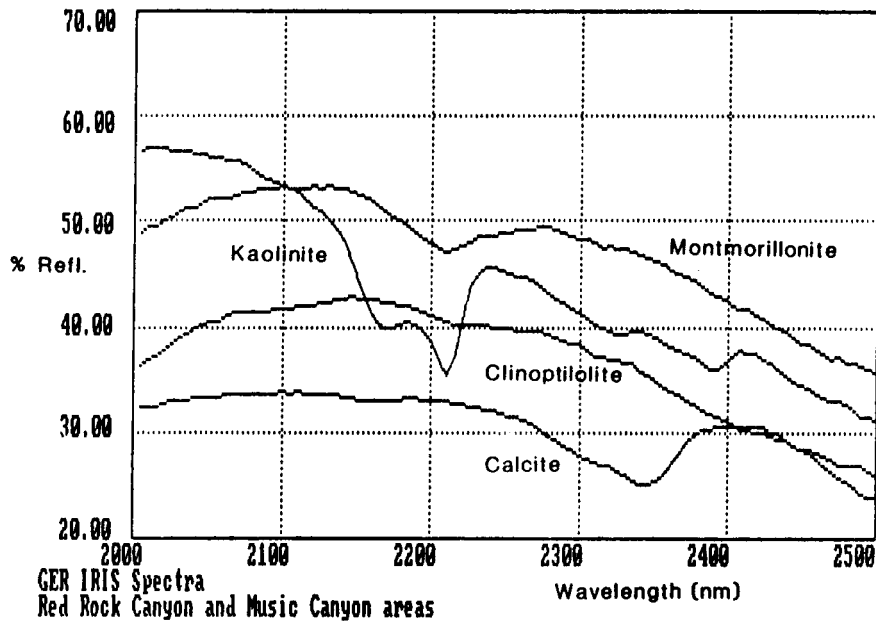


Fig. 1. IRIS spectroradiometer curves for samples collected along the AIS flight line, Hot Creek Range, Nevada.

the large volume of AIS data (128 bands by 32 pixels by the number of lines in the data set) and the low signal-to-noise ratio, desirable analysis methods are those which isolate the noise from the significant data, those which take a minimum of computer time, and those which are compatible with many users' system architecture, operating system, compiler, and peripherals.

PRINCIPAL COMPONENT ANALYSIS

Principal component analysis has been used for many years to enhance geologic features on Landsat Thematic Mapper (TM) or TM simulator imagery (Abrams and others, 1983; Conel and Alley, 1985). A principal component analysis decreases the dimensionality of the data without losing significant information. The correlation between variables is reduced to produce a more fundamental set of independent variables. The first component accounts for the greatest amount of total variance; components 2 and higher contain successively less variance. In areas of low vegetative cover, spectral variation in principal component images produced from TM-type imagery has often been correlated with changes in lithology.

Principal component analyses were executed on 512 lines of AIS data from the Music Canyon area and 512 lines from the Red Rock Canyon area. Three separate

principal component analyses were performed on the first 16 bands, 7 intermediate bands, and the last 16 bands from each of the two localities. The purpose of executing three analyses was to isolate significant mineralogical information from different parts of the spectrum and place it into the PCs with the greatest amounts of variance. The first PC analysis was performed using the first 16 bands (2048 to 2188 nm) as input, where kaolinite has an absorption feature. In the second, bands 12 through 18 (2151 to 2206 nm) were utilized to include longer wavelength clay absorption features. The last 16 bands (2197 to 2337 nm), where carbonate and clinoptilolite absorption features are present, were used in the third PC analysis.

From a series of experiments using different AIS bands as input to the principal component analysis, it was found that the number of bands used as input must be balanced against the amount of noise in the data set and the number of significant spectral features expected in that portion of the spectrum. The input of fewer bands into the principal component analysis results in a higher concentration of noise in PCs 2 and 3, making them less useful. Using a large number of bands as input into the PC analysis, from portions of the spectrum where many different absorption features are located (for instance clay minerals and calcite), causes the segregation of significant spectral information into higher number, noisy PCs.

The scaled and Gaussian stretched images of the 16 principal components (Figures 2a and 2b) of the Music Canyon area illustrate that PC 1 accounts for the greatest percent of the total variance (97 percent). PC 2 contains 2.5 percent of the total variance while PC 3, 4, and 5 each contain less than 0.5 percent. While there is significant information in PCs 3, 4, and 5, much of the information content is masked by noise. Horizontal striping accumulates in PC 3 and 4, while random noise collects in higher number PCs.

From an analysis of eigenvectors for both the Red Rock Canyon and Music Canyon images, it was found that each of the 16 input bands contributes equally to PC 1; PC 1 is a relative albedo image which also contains information on aspect and slope. PC 2 and, to a lesser extent, PC 3 contain the most significant information on mineralogy and surficial cover. The AIS bands which are highly correlated with PCs 2 and 3 (Table 1) are, most often, those bands located adjacent to spectral absorption features for kaolinite, montmorillonite, calcite, and clinoptilolite.

A color composite which effectively shows the distribution of kaolinite and calcite (limestone) in the Music Canyon area was produced using PC 2s and PC 3s from the three separate principal component analyses (Feldman and Taranik, [b], in press). Density slicing PC 2 images

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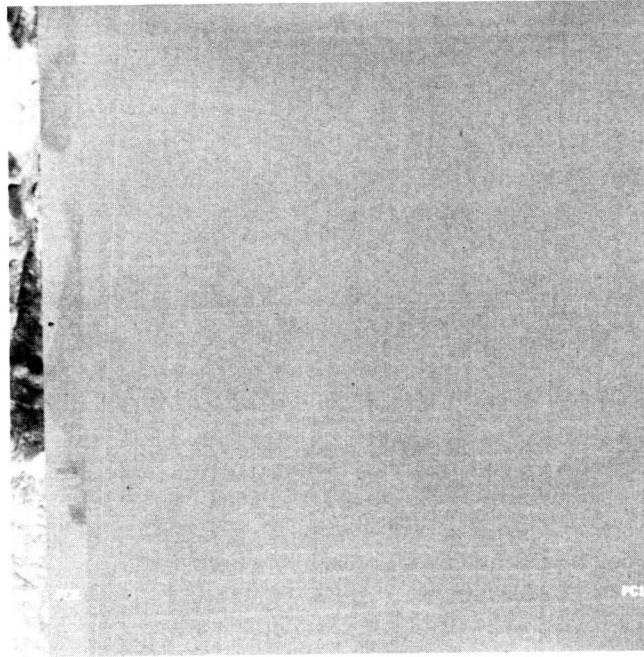


Fig. 2a. Principal components 1 through 16 (left to right) using the first 16 AIS bands in the fourth grating position as input. Real values scaled and converted to byte data for display.

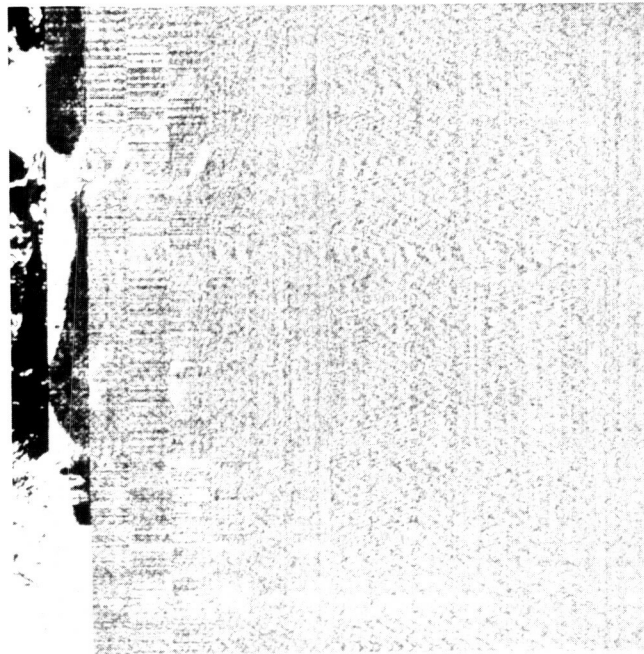


Fig. 2b. Principal components 1 through 16 (left to right) using the first 16 AIS bands in the fourth grating position as input. Gaussian stretch applied.

Table 1. AIS bands in the fourth grating position
which are highly correlated with principal
components 2 and 3

MUSIC CANYON SCENE

PC	AIS band	
	Band no.	Wavelength midpoint (nm)
Principal component analysis on bands 1 to 16		
2	14, 15, 16	2169, 2178, 2188
3	10, 11	2132, 2141
Principal component analysis on bands 12 to 18		
2	17, 18	2197, 2206
3	18	2206
Principal component analysis on bands 17 to 32		
2	--	--
3	30, 31, 32	2318, 2328, 2337

RED ROCK CANYON SCENE

PC	AIS band	
	Band no.	Wavelength midpoint (nm)
Principal component analysis on bands 1 to 16		
2	14, 15, 16	2169, 2178, 2188
3	3, 4	2067, 2076
Principal component analysis on bands 12 to 18		
2	17, 18	2197, 2206
3	18	2206
Principal component analysis on bands 17 to 32		
2	31, 32	2328, 2337
3	28, 29	2300, 2309

was also found to be very effective for mineralogical discrimination.

A similar method was used to produce a principal component image for the Red Rock Canyon area. The color composite image which most successfully separated kaolinite and montmorillonite-clinoptilolite alteration zones was formed using PC 2s from the three principal component analyses.

CONCLUSIONS

The most appropriate technique for applying principal component analysis to high spectral resolution data sets is dependent on the signal-to-noise ratio and on the width of significant spectral features of minerals which may be present. Input bands should be from portions of the spectrum where significant spectral features of minerals are located. This method cuts down on the amount of computer time needed to perform the principal component analyses.

For a signal-to-noise ratio of about 40:1, as in the Hot Creek AIS data set, in an area containing clay, zeolite, and carbonate minerals, it was found that three separate PC analyses, using the first 16 AIS bands, 7 intermediate bands, and the last 16 bands as input, was the most efficient technique. Most of the mineralogical information was found to be contained in PC 2s. PC color composites and density sliced images, composed primarily of PC 2s, yielded good mineralogical separation in the Red Rock and Music Canyon areas.

Principal component analysis is an effective way to separate argillic alteration, zeolite, and carbonate mineral localities using high resolution remote sensing imagery. PC analysis separates out relative albedo and aspect and slope effects, mineralogically significant information, and noise in the Hot Creek Range AIS data set. Although principal component analysis is computer-intensive, algorithms for PC analysis are already implemented on most image processing systems, and major reprogramming is not required. PC analysis methods are a viable option for many users of multidimensional spectral data.

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